Feasibility and Cost Study on VOIR SAR Data Transfer via a Bent Pipe Link

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An INTELSAT/DOMSAT double-hop bent pipe link for the VOIR (Venus Orbiting Imaging Radar) SAR (Synthetic Aperture Radar) imaging data transfer from DSS 43 and 63 to JPL is investigated. The cost for the bent pipe transfer is estimated and compared to that for the presently planned tape-record/airfreight-the-tape transfer method. This study is based on the mission plan available in May 1979.

I. Introduction

This article summarizes the result of a study on the relative costs of two methods for the VOIR (Venus Orbiting Imaging Radar) SAR (Synthetic Aperture Radar) data transfer from overseas Deep Space Stations (DSS) to Goldstone or JPL. The present plan is to tape-record the SAR data at DSS 14, 43 and 63 and then to airfreight the tapes to JPL. The other method is to transfer the SAR data from the overseas stations to Goldstone or JPL via a bent pipe link (an INTELSAT/DOMSAT link) and then to tape-record the data at either Goldstone or JPL.

The bent pipe concept for the overall DSN data transfer has been studied at JPL and a bent pipe system study for the Galileo/IUS (third stage) is also available. However, this study is conducted with emphasis on the comparison of the relative costs for the bent pipe and the presently planned tape-record/airfreight method of VOIR SAR data transfer.

The results contained in this article are based on the VOIR mission plan available in May, 1979. Throughout the article, the maximum SAR data rate of 7.33 Mbps is assumed instead of 1 Mbps data rate of a new reduced scope mission plan.

One of the original objectives of this study was to examine the possibility of eliminating the digital tape-recording requirement at the overseas stations, since the trend at DSN stations is toward unattended operation. Also, the quality control of the high-capacity digital tape-recorder operation may be improved at a central point, i.e., at JPL or Goldstone. However, the study indicated that the cost of the bent pipe method exceeds that of the tape-record/airfreight method by approximately a factor of 10.

In Section II, the presently planned data transfer method and its cost estimate are discussed. In Section III the characteristics of the INTELSAT/DOMSAT double-hop links and the implementation cost are presented. In Section IV, the two data transfer methods are compared.

II. Planned VOIR SAR Data Transfer

In this section, the presently planned VOIR SAR imaging data transfer method is described and its cost estimate is presented.

A. Planned Strategy

The SAR imaging data is transmitted to DSS 14, 43, or 63. In this study, it is assumed that the SAR data has the maximum data rate of 7.33 Mbps and is convolutionally encoded with a rate 1/2 and constraint 7 code. The SAR data on the X-band suppressed carrier BPSK signal will be demodulated by a Costas loop to be incorporated into Block III or IV DSN receivers. This modification will be part of the Multimegabit Telemetry Demodulator-Detector (MTDD) System.

The noisy SAR data symbol streams will be detected by a Symbol Synchronizer Assembly (SSA) and then decoded by a Maximum Likelihood Convolutional Decoder (MCD). The decoded data will be tape-recorded by the Digital Recording Assembly (DRA). The tapes then will be transported to the JPL mission support area. This procedure is shown in Fig. 1.

B. Cost Estimation

The estimated cost of the presently planned VOIR SAR data transfer is summarized in Table 1.

In this estimate, the items required for both methods of data transfer are excluded since our objective is really to determine the cost differential between the two methods. For example, the cost for tapes, implementation of the MTDD System and the basic DSN operation and maintenance costs are not considered. Thus, the cost estimate shown in Table 1 consists of the tape-recording cost and the delivery cost.

The decoded SAR data will be tape recorded through the DRA. The DRA can be operated at various speeds. Typically, 15 inches per second (ips) will be used here for cost estimation purposes. At a speed of 15 ips, the DRA can record data up to an 8 Mbps rate. A typical tape to be used is 0.5 in. wide and mounted on a 16-in.-diameter reel which contains 12,500 ft of tape. The approximate weight of the tape is 5 lb. The tape can record for approximately three hours at 15 ips.

The DRA has to be upgraded to support future high rate data return requirements such as the SAR data link from the VOIR. The upgrading cost for three DRA's (one each at DSS 14, 43 and 63) is approximately $75,000. The DRA tape recorder head should be replaced after every 3,000 hr of operation at 15 ips. The cost estimate is for one replacement per year at each DSS. Eight hours of DRA operation per day is assumed. The cost includes one new recording head ($6,000) and new reproducing head ($7,000) at each DSS. The DRA maintenance and operations costs are based upon normal operation. Assumptions for these cost estimates are indicated in Table 1.

At DSS 43 and 63, it is assumed that three tapes per day will be recorded. The tapes will be delivered to the nearest international airport and sent by commercial airline airfreight to Los Angeles (LAX). The delivery cost between an overseas DSS and an international airport is included in the item "other manpower" in Table 1.

III. Bent Pipe Data Transfer

The bent pipe link under consideration is a link from the VOIR to either DSS 43 or 63 and then from DSS 43 or 63 via an INTELSAT/DOMSAT double-hop link to Goldstone or JPL. A general bent pipe link description, possible subsystem interfaces in the link and cost estimate are discussed in this section.

A. Bent Pipe Link Description

The VOIR SAR data is transmitted on an X-band downlink carrier with suppressed carrier BPSK modulation. The signal is received by Block III or IV receivers at DSS 43 and 63. Then it is processed by a Symbol Synchronizer Assembly (SSA) and Maximum Likelihood Convolutional Decoder (MCD). The decoded data should be transmitted to either an existing INTELSAT Earth terminal or to a new INTELSAT Earth terminal on the DSS 43 or 63 site. The link from DSS 43 or 63 to an existing INTELSAT Earth terminal may be either a microwave link or a coaxial cable. The data may be QPSK-modulated to reduce BPSK signal bandwidth in half before transmitting it to the INTELSAT spacecraft. The data is usually modulated onto the standard 70 MHz IF carrier. Generally, frequency division multiple-access (FMDA) is used for the access of the INTELSAT transponder.

The INTELSAT IV or IVA spacecraft uplink uses a nominal 6-GHz carrier frequency, and the downlink has a nominal 4-GHz carrier frequency. For INTELSAT V, both 6/4 and 14/11 GHz links will be available. The signal from DSS 43 or 63 via INTELSAT is received in an INTELSAT U.S. gateway Earth terminal. Generally it is downconverted to the 70-MHz IF frequency and transmitted to a nearby DOMSAT Earth terminal via a microwave link or coaxial cable. Collocation for an INTELSAT U.S. gateway Earth terminal and a DOMSAT Earth terminal will be discussed later. The ground communications links at the U.S. gateway stations are similar to those discussed above.

The signal from a DOMSAT may be received at either Goldstone or JPL. A new DOMSAT Earth terminal is required at Goldstone or JPL. The signal received at the DOMSAT Earth terminal at Goldstone may be demodulated, decoded and tape recorded at Goldstone. Another option would be to transmit the signal to JPL via a microwave link and then process and record it at JPL. The various options for the receiving end point of the bent pipe link will be discussed in Section III F. However, for this study the last option is assumed. The bent pipe route is described in Fig. 2.

B. Interface Between DSS and INTELSAT Earth Terminal

Since the distance from DSS 43 or 63 to the nearest INTELSAT Earth terminal is an important factor for cost estimation, the locations of Earth terminals are discussed here.

The locations of DSS 43 and DSS 63 are listed in Table 2. The existing Pacific INTELSAT Earth terminal closest to DSS 43 is located near Moree, Australia, north of Sydney. The nearest INTELSAT Earth terminal to DSS 63 is located in Buitrago, Spain, about 50 miles north of Madrid. Geodetic latitude and longitude of these INTELSAT Earth terminals are listed in Table 3. The "airline" distance from the DSS 43 to Moree is approximately 368 nmi and that from DSS 63 to Buitrago is approximately 50 nmi.

Figure 3 describes a possible configuration of subsystems at DSS 43 and 63. The VOIR SAR data is received and demodulated by a Block III or IV receiver. For the planned suppressed carrier transmission of SAR data, the Block III/IV receiver is planned to include a Costas loop.

The demodulated signal is fed to a SSA and then to the MCD. One of the advantages of demodulating, detecting and decoding at DSS 43 or 63 is the possibility of retransmitting the data using a QPSK signal format in the INTELSAT and DOMSAT links. Since the VOIR X-band telemetry data will be convolutionally encoded with rate 1/2 code, the data transmission bandwidth in the satellite links can be further reduced to one-fourth using decoding and QPSK modulation for the satellite links. The demodulated data is remodulated onto the standard 70-MHz INTELSAT IF.

If the DSS and the INTELSAT Earth terminal are not collocated, the modulated IF signal (70 MHz) is upconverted to a microwave carrier frequency and transmitted to a receiver located close to an INTELSAT Earth terminal. The received signal is downconverted to the 70 MHz IF frequency which can be easily interfaced with the INTELSAT Earth terminal equipment. Since the decoded data rate varies from a maximum of 7.33 Mbps to less than 4 Mbps for most of the nominal VOIR mission period, many off-the-shelf microwave link components are available for the VOIR SAR data transfer.

Unless new INTELSAT Earth terminals are constructed at the DSS 43 and 63 sites, new microwave links should be installed from DSS 43 to the existing Moree INTELSAT Earth terminal and from DSS 63 to the existing Buitrago INTELSAT Earth terminal. From DSS 43 to Canberra, a new wideband microwave link would have to be installed by Australian Public Telephone and Telegraph (PTT) authorities. This new microwave link would have to interface with existing television bandwidth microwave links from Canberra to Sydney to Moree. From DSS 63 to Madrid, a new wideband microwave link would have to be installed by Spanish PTT authorities. This would interface with existing television bandwidth microwave links from Madrid to Buitrago. However, it may be less complicated from a regulatory sense as well as more cost-effective to collocate new INTELSAT Earth terminals at DSS 43 and 63 sites. However, the Australian and Spanish authorities would have to agree to this.

C. INTELSAT Space Link

In 1985, two INTELSAT IV-A (F-3 and F-6) will be available in the Pacific region, and four INTELSAT V will be available in the Atlantic region. These INTELSAT's may be utilized for the bent pipe transfer of the VOIR SAR data in 1985. However, some of the "retired" INTELSAT IV and IVA may be reactivated for the period of the VOIR mission.

For the transmission of VOIR SAR data through an INTELSAT link, a QPSK/FDMA mode is desirable. With QPSK/FDMA mode transmission, approximately 9 MHz of the typical 36-MHz bandwidth of a transponder is required.

D. Interface Between INTELSAT and DOMSAT Link

The VOIR data from DSS 43 in Australia can be transferred via a Pacific INTELSAT satellite and can be received at a west coast INTELSAT U.S. gateway Earth terminal such as Jamesburg, California. Even though there is no DOMSAT Earth terminal presently in Jamesburg, the American Satellite Corporation (ASC) may install a collocated Earth terminal there. Thus, collocated INTELSAT and DOMSAT Earth stations at Jamesburg are assumed for the remainder of this article.

The VOIR SAR data from DSS 63 in Spain can be transferred via an Atlantic INTELSAT satellite and received at U.S. gateway Earth terminals at Andover, Maine, or Etam, West Virginia. At these locations, there exist ASC DOMSAT Earth stations which presently access the WESTAR domestic satellite.

The INTELSAT satellite downlink carrier frequency is received at one of the U.S. gateway Earth terminals and then downconverted to a standard 70-MHz IF. The IF signal, after a frequency upconversion, is then transmitted through a very short terrestrial microwave link. At the nearby DOMSAT Earth terminal, the received microwave carrier is again downconverted to a 70-MHz IF. After another frequency upconversion, the carrier is retransmitted to a DOMSAT satellite. This is illustrated in Fig. 4.

E. DOMSAT Space Link

Currently available domestic satellites are the Western Union WESTAR, the RCA SATCOM and the COMSAT/AT&T/GTE COMSTAR. In 1980, Advanced WESTAR by Western Union and SBS by Satellite Business Systems also will be available. All systems except SBS use the 6/4 GHz C-band; the SBS and a portion of the Advanced WESTAR systems will utilize 14/11 GHz K_u-band.

The bandwidth requirement for a DOMSAT transponder is also approximately 9 MHz, which is a quarter of a 36-MHz transponder when a QPSK/FDMA transmission method is used.

F. Receiving End Point, Goldstone or JPL

The receiving point for the bent pipe depends on where the demodulation, detection and the tape recording of the VOIR SAR data are performed. The different options are as follows:

(1) The received signal at a new Goldstone DOMSAT Earth terminal from DSS 43/63 via the INTELSAT/DOMSAT link is frequency converted and retransmitted to JPL via a terrestrial microwave link. The tape recording is then performed at JPL. The received signal from DSS 14 is also frequency converted and retransmitted via the same terrestrial microwave link and then tape recorded at JPL where signal processing takes place.

(2) This option is the same as (1) above except that another DOMSAT link is used between Goldstone and JPL instead of the terrestrial microwave link.

(3) A new DOMSAT Earth terminal is installed at JPL instead of at Goldstone. The existing RCA SATCOM Earth terminal at JPL might be used if allowed.

(4) A new DOMSAT Earth terminal is installed at Goldstone as an option (1), but tape recording is performed at Goldstone. The tapes are then transported to JPL via automobile for signal processing.

(5) This option is the same as (4) above except that the signal processing facility would be established at Goldstone, removing the need to transport tapes to JPL.

In this report only option (1) will be used as a guideline for cost estimation.

G. Cost Estimation

The cost estimate for the INTELSAT/DOMSAT double-hop bent pipe method is based on the model described in Section III-A. Some of the critical assumptions for the cost estimate are as follows:

(1) Demodulation, detection and decoding are performed at each DSS.

(2) 9 MHz of bandwidth, i.e., a quarter of a 36-MHz satellite transponder, is assumed. This bandwidth is estimated to be necessary for the maximum VOIR SAR data rate of 7.33 Mbps, with a possible convolutional encoding in the INTELSAT/DOMSAT channel with a 7/8 rate and some guard band allowance to protect against intermodulation interference.

(3) The cost estimate for the data transfer from an overseas DSS to an INTELSAT Earth terminal is not included here. As discussed before, there are two options. The first option is to use a terrestrial microwave link from each overseas DSS to the nearest existing INTELSAT Earth terminal. The other option is to install an on-site INTELSAT Earth terminal at each overseas DSS. In either option, the cost may be a significant part of the total bent pipe cost.

(4) A DOMSAT Earth terminal at Goldstone is assumed.

(5) The VOIR SAR data from DSS 14, 43 and 63 will be tape recorded at JPL where signal processing takes place.

(6) A megabit rate terrestrial microwave link from Goldstone to JPL is assumed. The cost estimate for this microwave link is based on a 5-Mbps simplex line.

With the assumptions stated above, the cost estimates for the bent pipe method are summarized in Table 4.

IV. Discussion and Conclusion

This study provides a cost comparison between the planned and bent pipe VOIR SAR data transfer methods. Even though some cost estimates are crude, the cost ratio is at least 5-to-1, with the bent pipe costs being highest. Depending on the TBD costs, the ratio could go up to 10-to-1. Table 5 summarizes the relative costs for the two methods.

Even though the communication satellite link costs have been steadily decreasing in past years, the bent pipe method for the VOIR SAR data transfer does not seem to be cost-effective at the present time. However, it should be noted that the cost of the planned method is expected to increase slowly in time, while the cost of the bent pipe method will almost surely decrease in the future.

This cost study is based upon a maximum 7.33 Mbps data rate for VOIR. However, it is expected that for most of the time, the data rate could be in the range of 1 Mbps, more or less continuously. Thus, with some ingenious Time-Division-Multiple-Access (TDMA) store-and-forward burst uplink from the DSS to the satellite, the cost could be shared with other NASA missions or with other users. It seems that a bent pipe should be studied in the context of several NASA missions rather than a single mission. Also, any requirements for totally unattended overseas DSS operations and/or real-time data transfer to JPL may reduce the relative cost of the bent pipe. Hence it would appear to be worthwhile to continuously monitor the relative costs of a bent pipe in the future.

Table 1. Cost for recording and tape transfer

	6 mo, $\$ \times 10^3$	1 yr, $\$ \times 10^3$	Remarks
Digital recording assembly upgrade (DSS 43, 63, 14)	75	75	
Tape recorder head (DSS 43, 63, 14)	Not required	39	1 replacement/DSS
Maintenance (DSS 43, 63, 14)	8	16	5 man hr/week/DSS $20/man hr
Operation (DSS 43, 63, 14)	88	175	8 man hr/day/DSS $20/man hr
Tape delivery			
DSS 43 → LAX			
Airfreight	5	10	
Other manpower	8	17	16 man hr/week $20/man hr
DSS 63 → LAX			
Airfreight	3	5	
Other manpower	8	17	16 man hr/week $20/man hr
DSS 14 → JPL	8	17	16 man hr/week $20/man hr
LAX → JPL	8	17	16 man hr/week $20/man hr
Subtotal	211K	388K	

Table 2. Locations of the 64-meter Deep Space Stations

Station	Location	Latitude, deg	E. Longitude, deg
DSS 14	Goldstone, California	35.426	243.111
DSS 43	Ballima, Australia (near Canberra)	−35.404	148.980
DSS 63	Robledo, Spain (near Madrid)	40.434	355.753

Table 3. Locations of INTELSAT Earth terminals near DSS 43 and DSS 63

INTELSAT Earth terminal		Latitude, deg	E. Longitude, deg
Moree, Australia	North of Sydney	29° 20′	149° 50′
Buitrago	50 miles north of Madrid	41° 0′	356° 20′

Table 4. Cost for VOIR bent pipe data transfer

Transfer link	$/mo × 10^3	Total for 6 mo, $ × 10^3	Total for 1 yr, $ × 10^3	Remarks
DSS 43 – INTELSAT Earth terminal	TBD	TBD	TBD	
DSS 63 – INTELSAT Earth terminal	TBD	TBD	TBD	
INTELSAT Link				
Australia – U.S. Gateway	42	250	500	Estimated costs for 9 MHz B.W.
Spain – U.S. Gateway	42	250	500	
DOMSAT Link				
U.S. Pacific Gateway – Goldstone	31	186	372	For 9 MHz B.W.
U.S. Atlantic Gateway – Goldstone	31	186	372	
Earth terminal at Goldstone				
Installation	15	15	15	Standard B (10-m) terminal
User charge	15	90	180	
M/W Link, Goldstone – JPL				
Installation	•	175	175	Estimated costs for 5 Mbps simplex
User charge	35	210	420	Termination charges $170,000 amortized over
Termination charge	•	153	136	60 months
Total[a]	•	1,515 +TBD[b]	2,670 +TBD[b]	

[a]The total cost does not include the tape-recording cost at JPL.

[b]TBD cost is in the range of $1 million.

Table 5. Cost summary for VOIR SAR data transfer from DSS 14, 43, and 63 to JPL

	6 mo, $ × 10^3	1 yr, $ × 10^3	Remarks
Currently planned tape recording and airfreight data transfer method	211	388	Includes the planned DRA upgrade cost
Possible VOIR SAR data bent pipe transfer method	1,515 +TBD	2,670 +TBD	Utilize INTELSAT/DOMSAT double-hop links from DSS 43 and 63 to Goldstone Include terrestrial microwave link from Goldstone to JPL TBD costs are significant

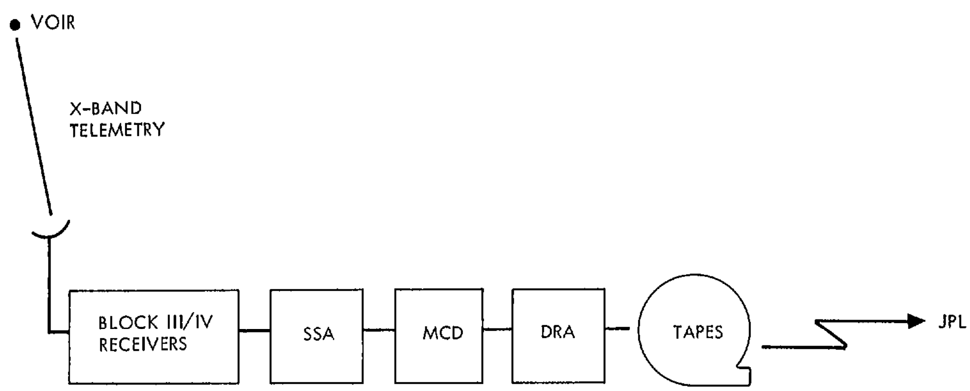

Fig. 1. The planned SAR data transfer strategy

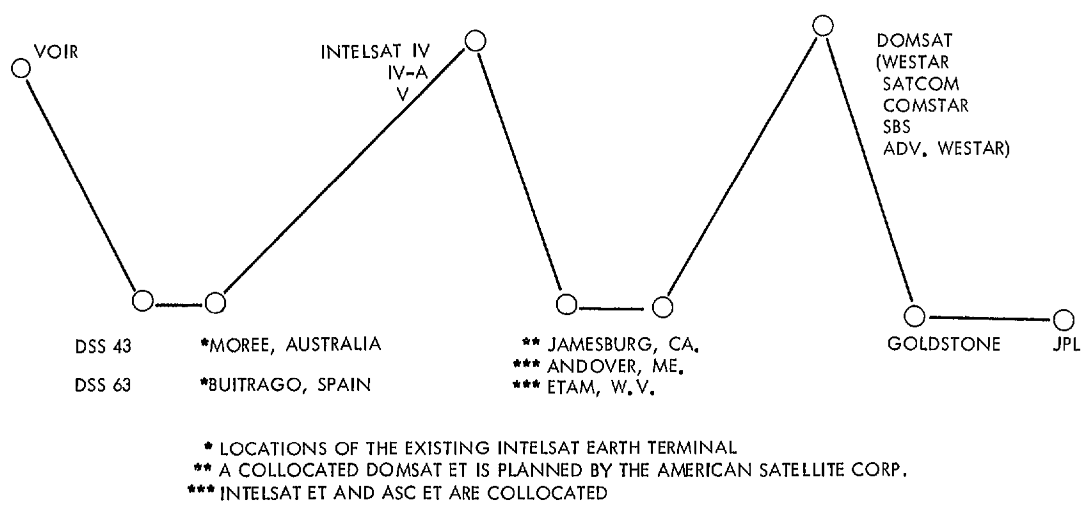

Fig. 2. Bent pipe route

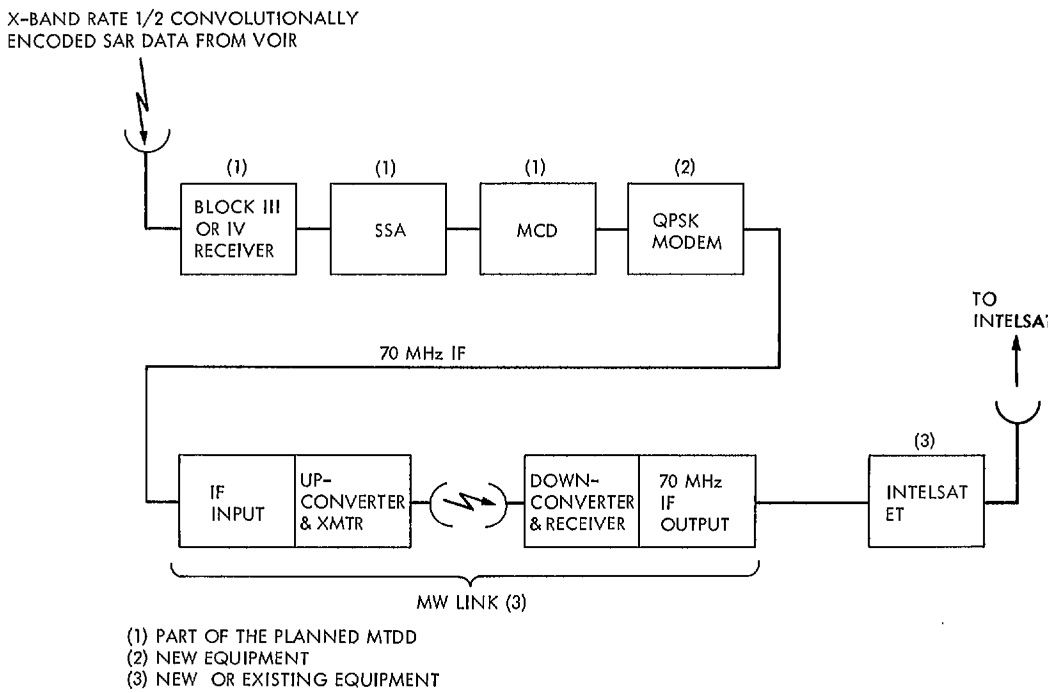

Fig. 3. Subsystems at DSS 43/63

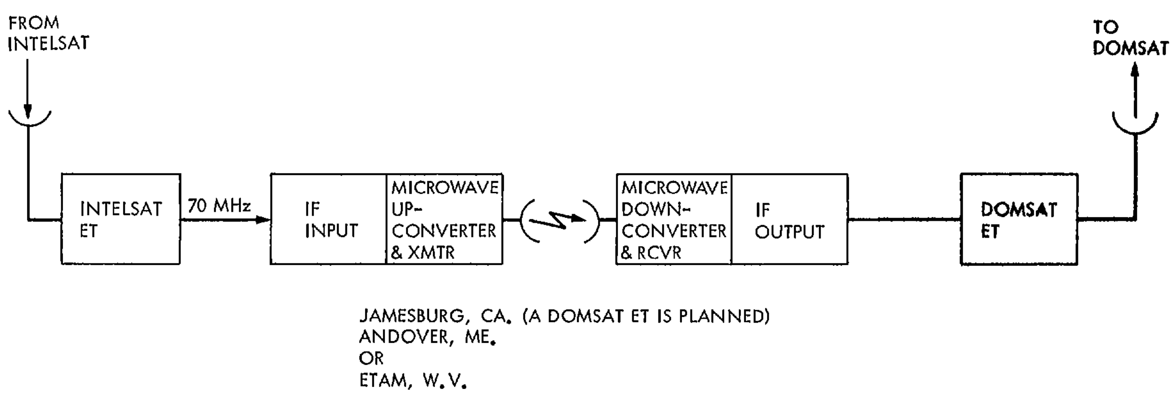

Fig. 4. INTELSAT/DOMSAT interface